Subcritical and Supercritical Operation of Innovative Thermal Mechanical Refrigeration System

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Abstract

Around 17% of the global generated energy is consumed for residential, commercial, and transportation refrigeration. The current cooling technologies utilize refrigerants with high Ozone Depletion and Global Warming Potentials. Furthermore, the current technologies are expensive alongside with toxicity and flammability hazards. On the other side, energy produced by combustion of fossil fuels result in substantial amounts of waste heat. So, it is necessary to develop new refrigeration technologies that utilize waste heat as a source of energy with eco-friendly refrigerants with zero ozone depletion potential and zero global warming potential. Also, the Thermal Mechanical Refrigeration (TMR) technology improves the energy efficiency of the source of waste heat system and minimizes the emissions of the carbon dioxide (CO_2). In this study, a novel thermo-mechanical refrigeration system is proposed. It operates with low-grade energy sources (such as waste heat) at temperature range of 60 ºC to 100 ºC. Furthermore, it has the advantage of working with low-frequency driver-compressor unit, which eliminates noise and increases its lifetime. Moreover, the TMR system is adaptable to commercial, transportation, and residential refrigeration applications.

Introduction

- Refrigeration and air-conditioning systems consume about 30 % of the generated electrical energy in Qatar [1, 7].
- Exiting thermal refrigeration systems usually require heat source temperature much higher than 100 °C [2].
- It is necessary to develop cooling system that has: very low effects on the environment, simple design, low cost, flexible performance, and could be powered by various sources of renewable energy and waste heat.
- A novel isobaric thermal mechanical refrigeration (TMR) system has been introduced [3]. It is powered by an isobaric engine developed by Encontech B.V. company [4].
- It directly converts the thermal energy into mechanical energy.
- It has a simple design which minimizes its initial and operation costs.
- It can be operated with heat source temperatures from 70 °C to 400 °C.
- It can be designed for various capacities and demands.
- Its performance is stable with the variation of the heat source temperature and/or with the variation of the cooling load.

Description

- The system consists of a vapor-compression cycle integrated with vapor power cycle (See Figure 1).
- The compression process is performed by an isobaric expansion engine (See Figure 1).
- The power stroke is performed by the high-pressure vapor generated in the heater.
- The hydraulic accumulator permits using arbitrary vapor pressure.
- The backstroke is performed by the pressure of the evaporator.
- It can be operated is subcritical mode or supercritical mode (See Figure 3).
- The regenerator can be used to improve the efficiency and to minimize the condenser size.

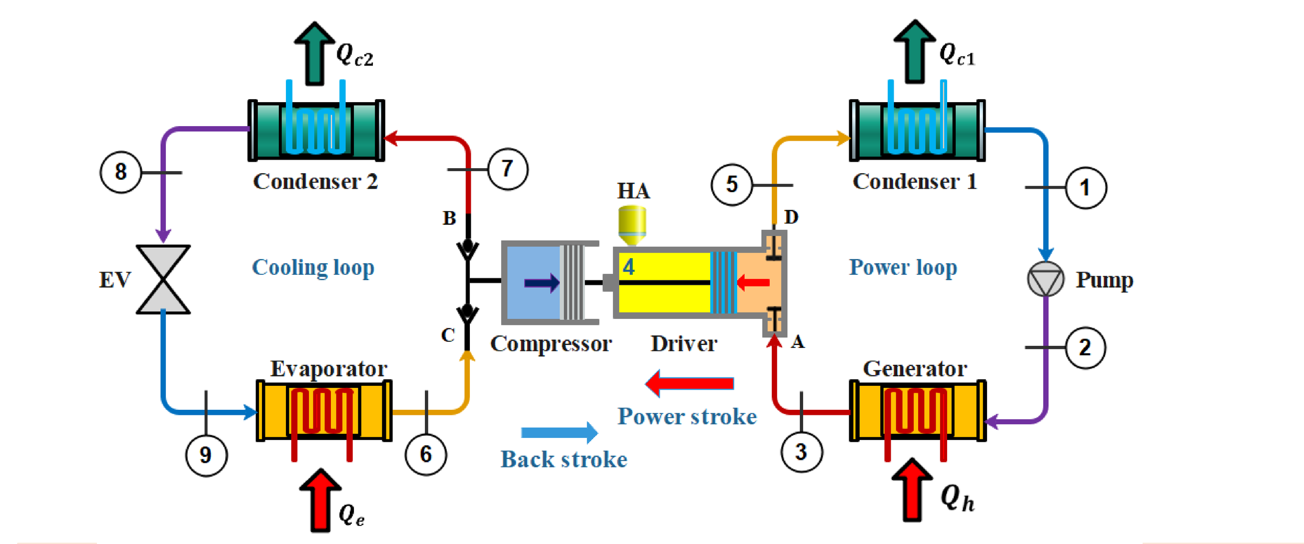

Figure 1. Schematic diagram of the regenerative thermo-mechanical refrigeration system.

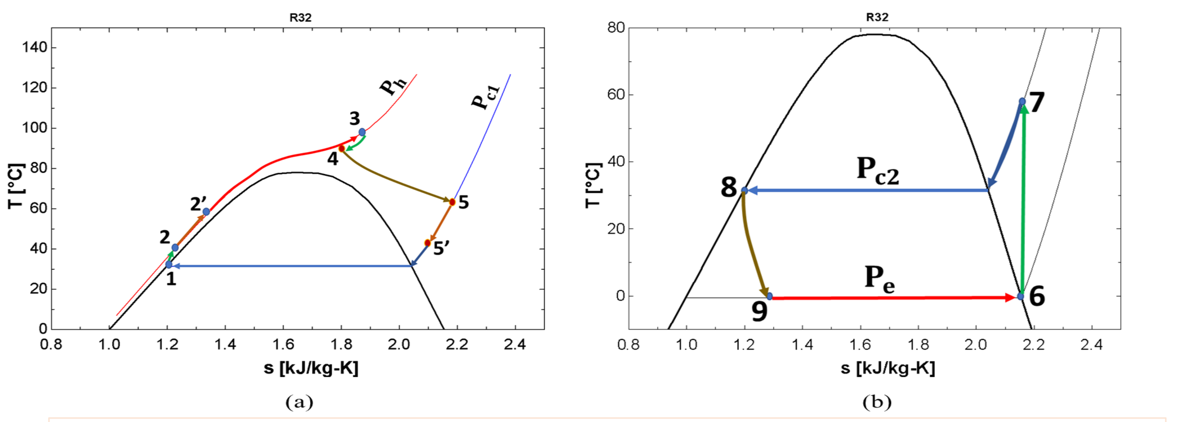

Figure 3. T-s diagrams of the power and cooling loops in supercritical mode.

Benefits of the study

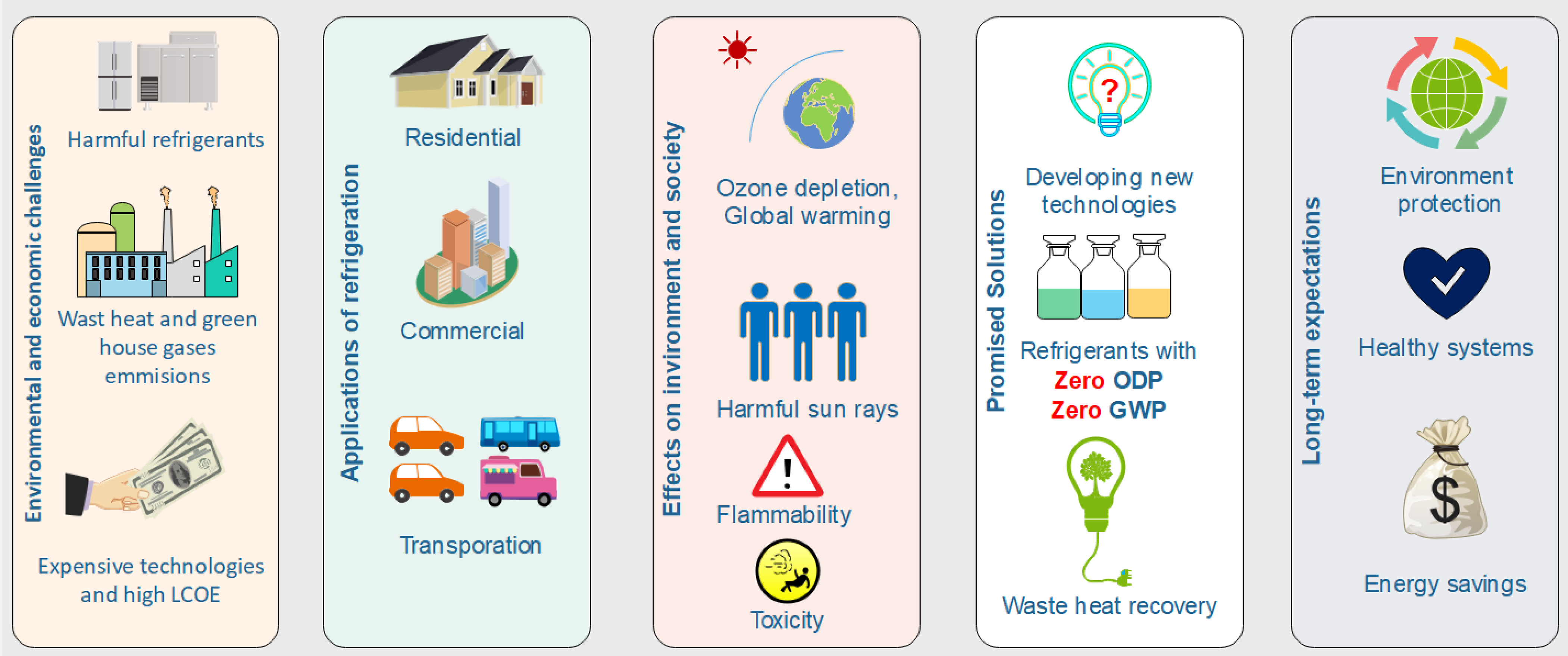

Figure 2. Challenges , applications, effects, and proposed solutions of the refrigeration technologies.

Results

- At heat source temperature from 70 ⁰C to 100 ⁰C, the subcritical mode is more advantageous than supercritical mode. In this range, using R707 in power loop with R32 in cooling loop provides maximum power efficiency of 7.8%, (See Figure 6).
- At heat source temperature higher than 100 ⁰C, the supercritical mode is more advantageous than subcritical mode. In this range, using R32 in power and cooling loops provides power efficiency of 10.8 % (with regenerator) and 9.6% (without regenerator).
- The size of the expander-compressor unit depends on four factors: pressure difference between the higher and lower pressures of the power cycle, the evaporator temperature, the condenser temperature and the cooling capacity of the cooling cycle.
- Systematic steps are performed to select the proper fluids for subcritical mode (See Figure 4) and supercritical mode (See Figure 5).
- Over the design range, the expander diameter range varies from 45 mm to 65 mm and the compressor diameter range varies from 72 mm to 80 mm for a cooling capacity of 2 kW to 6 kW (See Figure 7).

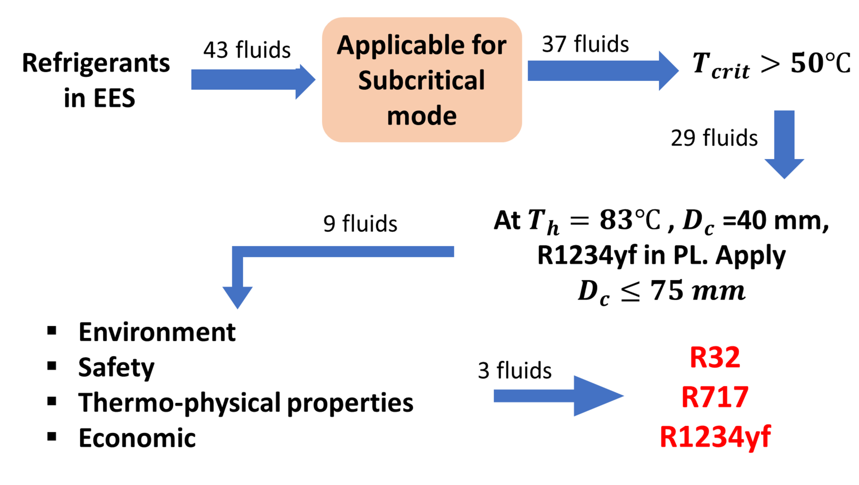

Figure 4. Steps of working fluid selection for subcritical mode [3].

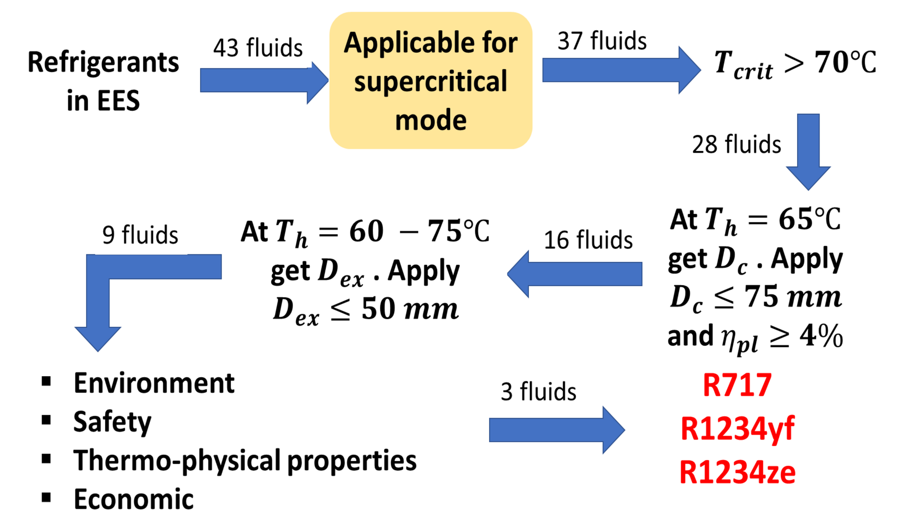

Figure 5. Steps of working fluid selection for supercritical mode [3].

Comparison

Table 1. Comparison between thermal refrigeration technologies

	TMR systems	ORC systems	Absorption systems	Ejector systems	Thermo-electric systems
Range of heat source temperature	60 – 100 °C	100 – 300 °C	90 – 220 °C	60-160 °C	N.A
Main advantages	• Low-grade heat source • Simple design (low cost) • Flexible capacity • Stable performance	• Proven technology • Electrical output	• Economic for large commercial applications	• Simple design (low cost)	• No moving parts. • No working fluids
Main drawbacks	• Moving parts (pistons, valves)	• High cost • Low expander efficiency	• Large size • Limited cooling	• Fluctuation at off-design conditions	• Very high cost 20,000 – 30,000 $/kW

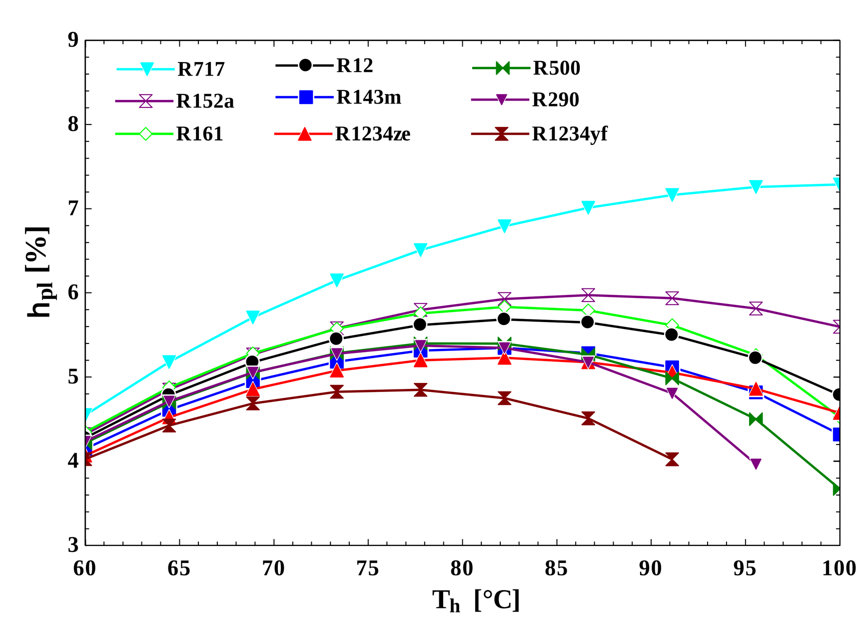

Figure 6. Power loop efficiency in subcritical mode [3].

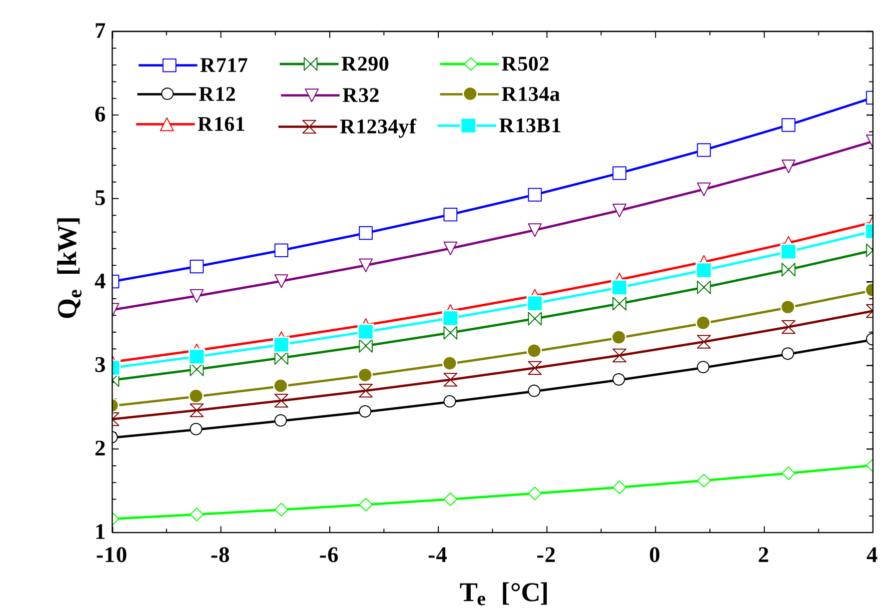

Figure 7. Cooling loop capacity in subcritical mode [3].

Conclusions.

- A novel thermo-mechanical refrigeration system is introduced.
- The proposed system able to operate with low-grade energy with temperature range of 60 ºC to 100 ºC.
- It can work with low-frequency which eliminate noise and increase the service time.
- Thermodynamic investigation of the system performance under subcritical and super-critical mode is applied and published.
- It is important to improve the control mechanism of the valves of the proposed system. It may be applied mechanically as shown in Figure 8.

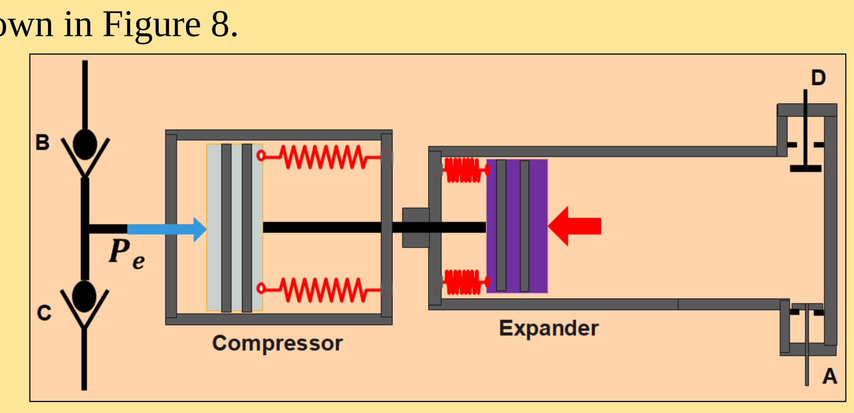

Figure 8. Mechanical valve control mechanism to be investigated in future work.

Acknowledgement

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